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An Interactive Educational Learning Tool for Power Electronics

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Abstract-- Power Electronics has continuously been a crucial part of Electrical Engineering; it is how we transmit and convert electric energy, hence it is desired to develop good fundamental basics of Power Electronics for Electrical Engineers. Therefore the main objective of this research work is to create a program that provides an interactive, user friendly and enlightening learning environment to assist users, undergraduate students to learn about Power Electronics. The program comprises a Graphical User Interface and when the program is executed, a detail labeled simulation graph of desired circuit is presented with user input parameters, embracing the relationship between the relative input/output voltage and currents. The program could potentially save tremendous amounts of time and be extremely useful for educational purpose. This paper will discuss the basics of Power Electronics, specifications, algorithm of the program, simulation results and case studies

Index Terms— power electronics, interactive educational learning, graphical user interface

I. INTRODUCTION

Delivering Power Electronic education to undergraduate students becomes challenging due to variety of applications and concepts and also limitations of the topics that can be learned by students within traditional courses.

Tutorial sessions may not provide enough information and knowledge for student to analysis power electronic circuits operating in a real case considering practical components and stray components in a circuit. Also steady state analysis of power electronic systems is not enough for undergraduate students; as real problems happens in real case when changing a load and input voltage may disturb a system and make it unstable.

Transient analysis of a power electronic system is difficult to deliver to undergraduate students based on mathematical analysis and modelling while using a simulation tool they can understand a dynamic performance of a system.

There is an interactive power electronic website where most of power electronic circuits can be simulated based on E-learning [4] but the limitations are: students should have access to internet and also they cannot change parameters by number.

The main aim of this research work is to help undergraduate students to learn about power electronics through a simple method to use an interactive program. In using this program,

undergraduate student can simulate circuits and gain more understanding about the circuit operations. Also it is desired to help lectures in teaching the basics and advanced topics in power electronics. Hence this program will benefit heaps for educational purpose where students can run the program in their computer without needing an internet.

This approach will improve the student's learning and understanding better compared to other methods in varies ways. Firstly, if a student wishes to simulate a power electronic circuit in MATLAB, it will require a decent amount of time to set up the circuit and also to obtain valid results. Hence this program provides a quick and simple path towards simulation. Secondly, compared to other PSIM demo versions, this program provides complete access, and hence any student can use this program fully for learning. In addition, for introductory level students, the simplicity of this program does not cause confusion to any unfamiliar simulation parameters.

It was decided that MATLAB is used to develop this program because of the easy access to MATLAB in universities around the world. In addition, MATLAB provides all the components to meet the specifications listed in Section 2.1.

Future development of this program is to implement and simulate the power electronic circuits using the "m-file" in MATLAB instead of "Power Simulator". This would increase the efficiency of the program and also decrease the size of the program.

The following section is an introduction to power electronics and the rest of this paper discuss about an interactive simulation tool based on MATLAB/SIMULINK to simulate different power electronic circuits.

Power electronics is present where the process and control the flow of electric energy needed. It is the application of electronic circuits to energy conversion. The aim of power electronics is to optimize the power efficiency, minimal size, minimal weight and meeting the requirements for user loads by modifying the voltages and currents. Fig.1 shows a block diagram of a power electronic system.

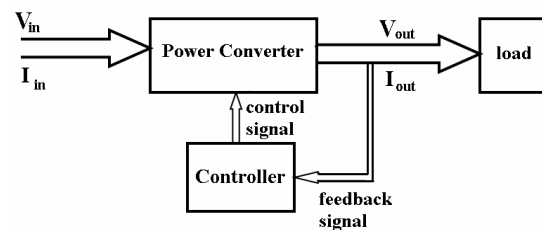


Figure 1: Block Diagram of a Power Electronic System

Power processors, depending on the application, the output of the load may have the following forms [1,2]:

DC – Regulated or adjustable magnitude.

AC – Constant frequency and adjustable magnitude or adjustable frequency and adjustable magnitude.

Power conversions (converters) consist of four different conversion functions as shown in Fig2 and described in below:

- **AC-DC (rectification)**
Possibly control DC voltage and AC current
Examples: Diode rectifiers and thyristor rectifiers.
- **DC-DC (conversion)**
Modify and control voltage magnitude.
Examples: Buck and Boost Converters.
- **DC-AC (inversion)**
Single and three-phase converters and different modulation schemes.
- **AC-AC (conversion)**
Cycloconverter, Matrix Converter, AC choppers

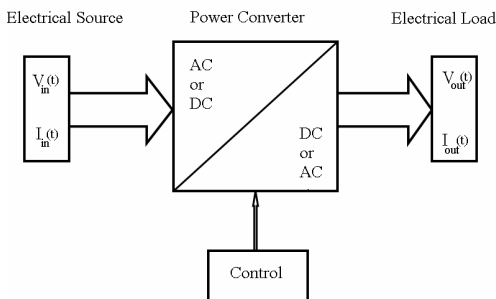


Figure 2: a Power Electronic System with Four Possible Conversions

Power electronics can be used in different categorizes such as:

1. Switch-mode (dc) power supplies and uninterruptible power supplies
2. Energy conservation
3. Process control and factory automation
4. Transportation

Power electronics are widely used in modern days in applications where power processing is required such as:

- Residential: Refrigeration and freezers, Air conditioning, Cooking, Lighting and Electronics.
- Commercial: Uninterruptible power supplies (UPS), Heating, ventilating, and air conditioning, Lighting, and Computers and office equipment.
- Industrial: Pump, Compressors, Machine tools, Welding and Induction heating.
- Transportation: Battery chargers for electric vehicles, Cars, Buses, Subways and automotive electronics including engine controls.
- Utility systems: High-voltage dc transmission (HVDC), Static var compensation (SVC), Supplemental energy sources (wind, photovoltaic), fuel cells, Energy storage systems and Induced-draft fans and boiler feed water pumps.
- Aerospace: Space shuttle power supply systems, Satellite power systems and Aircraft power systems.
- Telecommunications: Battery chargers and Power supplies (dc and UPS).

II. PROGRAM DESIGN

The program is designed according to the specifications to meet the requirements as described in the following section.

A. Specifications

A program that provides an interactive, user friendly and enlightening learning environment in Power Electronics is required. It is desired to produce a detail labelled simulation graph of desired circuit with user input parameters embracing the relationship between the relative input/output voltages and currents.

The inputs to the program are:

- Circuit selection
- Source voltage or/and frequency
- Load configuration and relative parameters
- Circuit device parameters

All Power Electronic circuits are to be implemented and modeled using the power simulator.

A Graphical User Interface is desired to provide a user friendly environment as well as linking between the user inputs and the power electronic circuits.

Error trapping logics are to be implemented to avoid the confusion caused when an error has occurred.

B. Design

After preliminary research, it was decided to implement the program in MATLAB as it provides all the components to meet the program specifications listed in Section 2.1. The resources provided by the MATLAB/SIMULINK Platform were used greatly in achieving the aim of this research work. SIMULINK is used as an environment to create the power electronic circuits by applying the in-built power components library. The GUIDE tool in MATLAB gives fast and simple method to create the Graphical User Interface required. One of the main reasons of using the MATLAB/SIMULINK platform is because the linking between the Power Simulator and the Graphical User Interface can be done efficiently. This is optimized by having a common “Workspace” in MATLAB to store the input/output variables, hence providing simpler and faster computation. In addition, MATLAB offers a straightforward approach to incorporate the sound and video clips and also animation in the program. Furthermore, MATLAB provides the possibility for future developments by implementing replacing the power simulator with m-files. Moreover, because MATLAB is used widely throughout different disciplines and around the world, it makes it easy to access MATLAB. Lastly, MATLAB gives straightforward instructions to execute the program.

MATLAB (Matrix Laboratory)

MATLAB is a numerical computing environment and programming language that allows users to plot functions and data, implement algorithms, creation of user interfaces and interfacing with programs in other languages [3]. In this research work MATLAB is used as a foundation program and

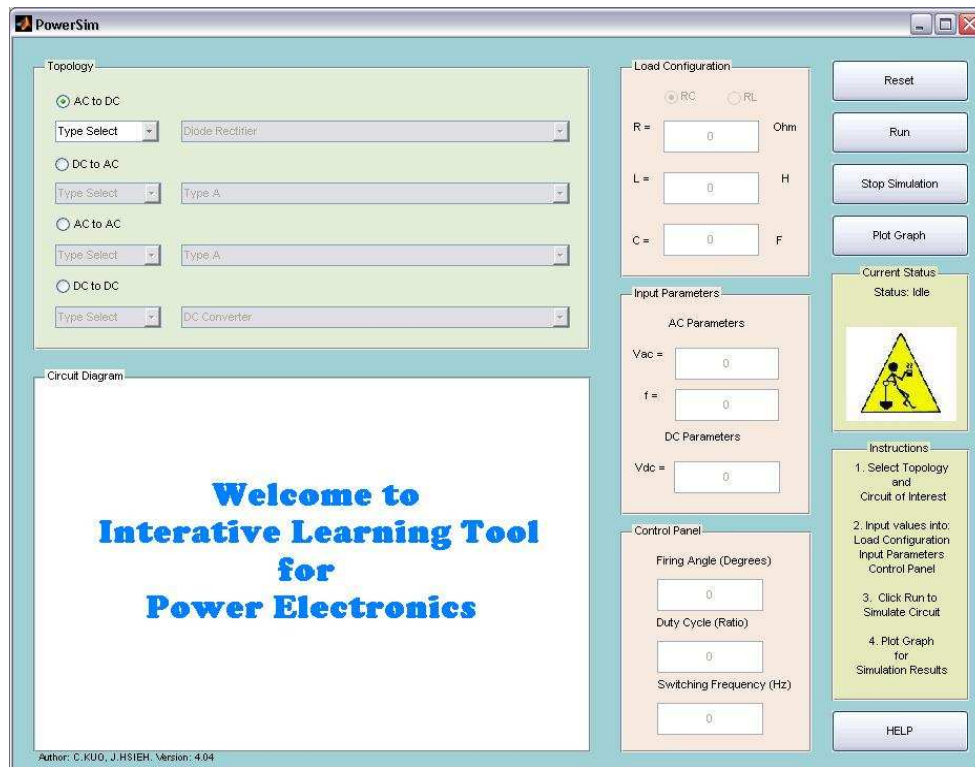


Figure 3: Main Graphical User Interface Layout

providing access to variables to all sub programs by using the “Workspace”.

SIMULINK

SIMULINK is a platform for multi-domain simulation and Model-Based Design for dynamic systems, providing an interactive graphical environment and a customizable set of block libraries, and can be extended for specialized applications. In this research work SIMULINK is used to create and model the Power Electronic circuits.

GUIDE

GUIDE, the MATLAB Graphical User Interface environment provides a set of tools for creating graphical user interface (GUIs). The GUIDE Layout Editor can easily lay out a GUI by clicking and dragging GUI components. Also, using the M-file editor, user can add code to the call backs to perform the functions requested

Program Layout

The Graphical User Interface is created using the GUIDE tool and it consists of eight (8) sections as shown in Fig.3.

- The Topology selection box divides power electronic circuits into four categories comprising AC to DC, DC to DC, DC to AC and AC to AC. Each category is then divided into sub categories. For example, AC to DC category is divided into diode rectifiers and thyristor rectifiers with different configurations; DC to DC category consists of buck, boost buck-boost, flyback and forward converters; and DC to AC consists of single and three phase converters with different modulation schemes

as well as current control techniques.

- The Load configuration selection box is designed to allow user to see the effects of different load configurations on the circuit, typically pure resistive, inductive, series RL or parallel RC.
- The Input parameter box allows user to enter appropriate input parameters such as AC source voltage, AC source frequency and DC source voltage.
- The Control panel box enables user to enter parameters to control devices such as the firing angle of a thyristor.
- The simulation buttons are clear value, run and plot graph. Simulation is executed when the run button is clicked and simulation graphs are plotted when the plot graph button is pressed. All values are cleared when clear value is pressed.
- The Picture box will display the image of selected circuit; this would help the user to understand the circuit configuration.
- The current status box will show the “current status” of the program. For example when the program is executing, the status box will show “Simulating...”.

The purpose of the HELP menu is to provide information to user on how to use the program and learning materials for further knowledge.

Power Electronic Circuits

All Power Electronic circuits are implemented and modelled in SIMULINK as an example is shown in Fig.4. After the user inputs are obtained, it is passed to SIMULINK for simulation. The results are then passed back to MATLAB. In this case, “*simpower system*” library

should be available in SIMULINK or the circuits can be simulated using m-files.

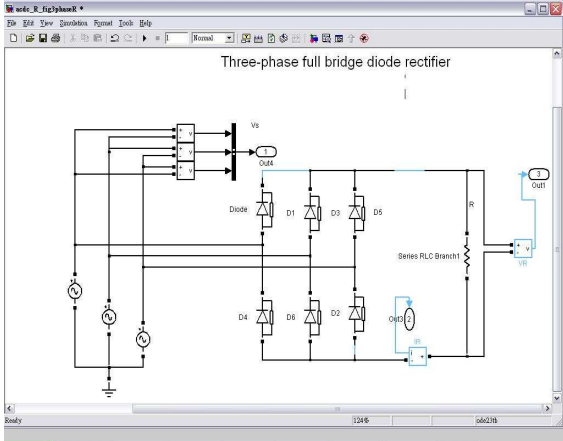


Figure 4: Three-phase Full Bridge Diode Rectifier Circuit in SIMULINK
Circuit Image

Circuit images are displayed in section 6 of the GUI layout as discussed in section 2.2.7. The purpose of displaying the circuit image is to assist users to understand the configuration of the actual circuit and the load. Once a user selects a topology, a circuit diagram associated with that topology is appeared in this box to help the user as shown in Fig.5.

HELP menu

The purpose of the HELP menu is to guide users on using the program and providing learning materials. Different topologies with different configurations have been described with animations to show the switching states of power electronic circuits with a short description.

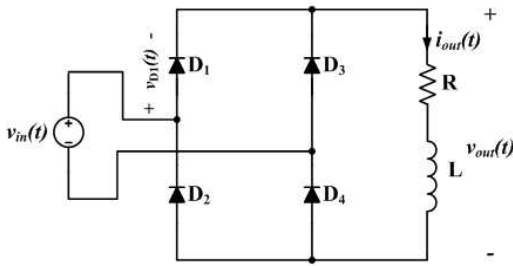


Figure 5: Example Circuit Diagram of Single-phase Diode Rectifier with RL Load

III. PROGRAM ALGORITHM

In order to meet the specifications described in Section II.A linking to the program is required between the Graphical User Interface and SIMULINK. The Algorithm is shown as below.

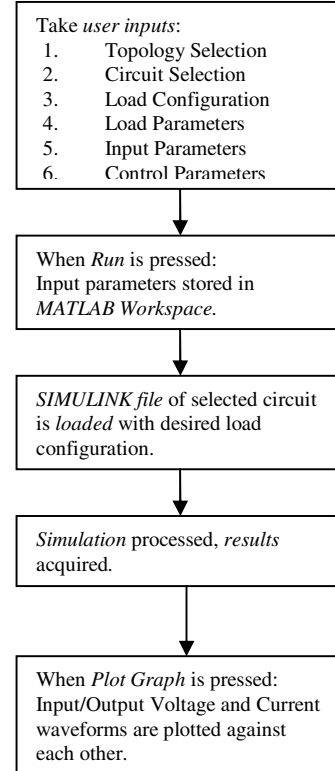


Figure 6: Algorithm Flow Chart of Program

A. Linking between GUI and SIMULINK

The linking between the Graphical User Interface and SIMULINK is done by first storing the user input parameters in the MATLAB workspace. The parameters are then passed to SIMULINK to model the Power Electronic circuit. After the waveform have been computed, it is passed back to the workspace and plotted.

Step 1:

The program asks for user inputs, these include Topology Selection, Circuit Selection, Load Configuration, Load Parameters, Input Parameters and Control Parameters. Unless all the inputs are in correct format, the program will not execute and will ask the user again to re-enter the correct format.

Step 2:

When run is pressed, the variables are stored in the MATLAB Workspace for further process. The program can not be stopped at this stage.

Step 3:

Depending on the topology selected, SIMULINK circuit file is loaded with selected load configuration and user inputs.

Step 4:

Simulation of circuit is carried out. At this stage the current status box will show "Simulating Circuit...". After the simulation has finished, the results are passed back to MATLAB Workspace and the current status box will show "Simulation Finished".

Step 5:

Upon Plot is pressed, the results stored in MATLAB Workspace are plotted against each other, typically input voltage, input current, diode voltage, output voltage and output current to enhance the relationship between the voltage and currents.

B. Error trapping

Before the variables are stored in Mtlab workspace in Step 2, they are checked for consistency with their respective requirements. If they do not meet these requirements (ie, a letter entered instead of a number) the user is alerted and requested to enter in valid information. Also when the user has made a selection of circuit, the non-relatives input boxes are grey out. This is to prevent any confusion to the user and improve program stability.

C. Output Results

The output of this program is to plot a detail labelled simulation graph of desired circuit with user input parameters embracing the relationship between the relative input/output voltage and currents. This will help users to examine the circuit operations and hence increase their understanding of the circuit. Fig.7 shows a simulation result of a three-phase system. In fact, student can change the parameters and see the effect of each variable on output voltage or current.

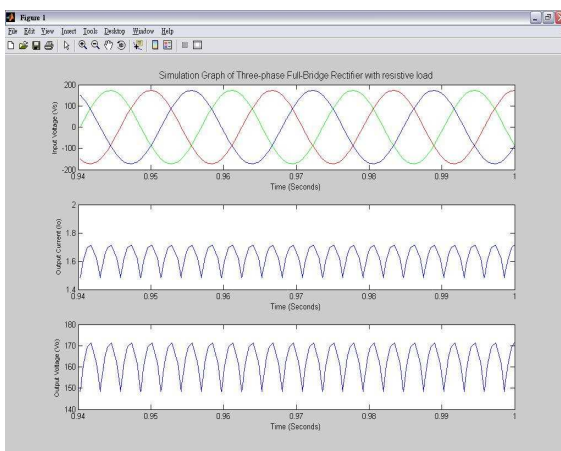


Figure 7: Simulation results

IV. USER MANUEL

The section below describes how to start the program and how to use the program.

A. Starting the Program

To start the program:

1. Open MATLAB
2. When MATLAB has been loaded, change the Current Directory in MATLAB to where the program is located

3. Type in “powersim” in the Command Window or drag the m-file “powersim.m” into the Command Window

B. Using the Program

To use the program:

1. Select Topology and then desired circuit
2. Enter user input parameters
3. Select Load Configuration and enter parameters
4. Enter Control Panel parameters if necessary
5. Click on Run
6. After the Simulation has finished, click on Plot Graph

C. Case Study 1

For instance, a user were to simulate a Three-phase full bridge diode rectifier circuit with resistive load, first choose “AC-DC” and “Diode” category from the topology selection box and followed by “Three-phase full bridge diode rectifier”.

As shown in figure 8, the non-relative inputs to the selection are grey out. Then identify the desired load configuration, in this case because it only has one load configuration the user would not need to choose the load configuration, and the appropriate parameters. Next enter the user input parameters, in this case it would be AC voltage source and source frequency. After that, click on run and wait for the simulation to finish, shown in the status box “Simulation Finished”. Lastly, click on plot graph.

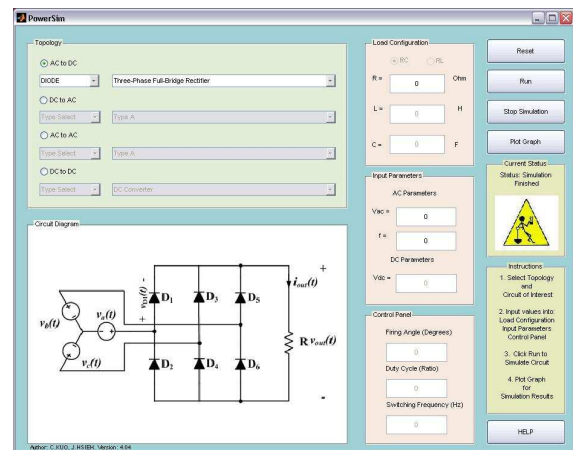


Figure 8: A Case Study for AC-DC Converter

D. Case Study 2

Now, if a user wants to simulate the same circuit as the one in the previous case study, but without entering any inputs; by pressing run bottom, an error box will pop-out as shown in Fig.9 to indicate to the user that there are missing inputs and what they are. Until all inputs are correctly entered, the program will keep error checking for inputs.

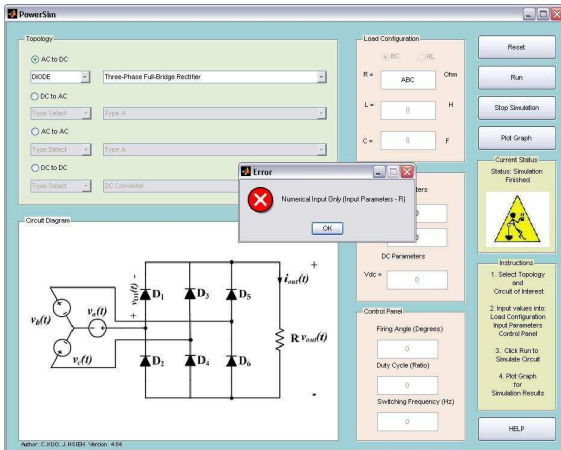


Figure 9: A case study

V. USER MANUAL

The intention of this program would be vastly helpful to users who are not familiar with Power Electronics and to learn through a simple and user friendly environment. Also, it is extremely useful for educational purpose in the case of lecturers demonstrating in class and students learning in their own time. In addition, it can be further developed to meet advanced requirements such as simulation of dynamic power electronic circuits.

VI. ACKNOWLEDGMENT

This undergraduate research work was assisted by three PhD students, Arash Abbasalizadeh Boora, Jafar Adabi and Alireza Nami in creating the power electronic circuits in SIMULINK.

VII. REFERENCES

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